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TESTS ON THE PERMEABILITY OF CONCRETE

BY

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RESEARCHES IN APPLIED MECHANICS
EDWARD R. MAURER, PROFESSOR OF MECHANICS

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TESTS ON THE PERMEABILITY OF CONCRETE

I. INTRODUCTION

This bulletin is a report of a series of permeability tests made in the laboratory for testing materials at the University of Wisconsin during the summer and fall of 1908. The object of the tests was to determine the efficiency of some of the commercial compounds used for the water proofing of concrete.

Tests were made on fourteen compounds, each compound being subjected ordinarily to pressures of approximately 20 lbs/in^2 and 40 lbs/in^2. The duration of the test was usually three days, and a record was kept of the amount of water entering the concrete.

In order to ascertain the effect on the strength of concrete of the compounds which are added to the body of the concrete, compression specimens were made. Three of the compounds were tested in this manner, the specimens being broken at the ages of approximately 1, 2 and 10 months.

This work is a partial repetition and a continuation of a thesis completed by S. R. Hatch and H. E. Ketchum of the class of 1907. Due acknowledgment is made to them for their valuable assistance in designing the apparatus used for these tests. M. O. Withey and A. H. Miller, of the department of mechanics, also rendered effective service in performing the tests. J. Glaettli and A. E. Meinecke of the classes of 1909 and 1910, respectively, made the drawings and tables for this bulletin.

II. CONCLUSIONS

The following conclusions are drawn as the result of the experiments:

1. Unless extreme care is taken in proportioning, it is necessary that some form of water proofing be used for a 1 : 3 : 5 concrete for pressures from 20 lbs/in² to 40 lbs/in².

2. For nearly all specimens the rate of flow decreased rapidly with time. This was especially marked in the case of the mortar coatings and was due in part to their dry condition.

3. All of the surface paints were quite satisfactory at pressures of 20 lbs/in². When subjected to pressures of 40 lbs/in², Des Moines Elaterite No. 60 and Universal Damp-Proof Compound proved unreliable. The mixture of Flexible Compound and white lead gave good results at both pressures. Century Cement Fluid was not tested at the high pressure and while Antihydrine gave only a small flow at 40 lbs/in², the results can not be compared with those of the other compounds because the test was carried on under different conditions.

4. Water proofing materials composed of layers of felt, burlap, or tarred paper, cemented together with a compound, gave excellent results at the high pressure. Not one of the specimens treated with Hydrex Felt and Compound, Siastex Fabric No. 2 and Pitch, and Dehydratine No. 4 and tarred roofing paper showed any appreciable flow.

5. Coatine was practically impermeable at the two pressures.

6. The mortar coatings in the case of Antihydro gave good results at both pressures, there being practically no flow after the first 24 hours. It is possible, however, that its effectiveness was due partly to the method of applying the mortar. For waterproofing used in this manner, it would seem desirable to apply the mortar in two layers after first covering the concrete with a neat cement slush coat. The plain mortar with a neat cement wash was effective at a pressure of 20 lbs/in² but proved unreliable at 40 lbs/in². No doubt a plain mortar coating would prove satisfactory in water proofing concrete at high pressures providing it be applied as just described.

7. Waterproofing compounds that are added to the body of the concrete are worthless at pressures from 20 lbs/in² to 40 lbs/in² unless great care be used in proportioning.

8. Limate, when replacing 10 per cent to 22 per cent of the weight of cement, and Medusa Water-proof Compound equal to 2 per cent of the weight of the cement do not impair the compressive strength of 1 : 3 : 5 concrete. On the other hand, Aquabar equal to 4 1/6 per cent of the mixing water reduces the strength of 1 : 3 : 5 concrete by percentages varying from 36 per cent to 54 per cent.

III. DESCRIPTION OF APPARATUS AND MATERIAL

Apparatus:—The apparatus which was designed for these tests consists essentially of eight six-inch pipes filled with concrete and a pipe system connected with air and water reservoirs. Fig. 2 shows in detail the mold and attached casting and Fig. 1 is a general drawing of the pipe system for four specimens, the apparatus for the remaining four specimens being the same as shown.

The molds shown in elevation in Fig. 1 and in section in Fig. 2 were six-inch wrought iron pipe, 12½ inches long, with a cast-iron flange screwed to the upper end. In order to prevent the passage of water between the pipe and the cement lining ten or twelve V-shaped grooves were cut in each pipe, each groove extending around the inner surface of the pipe.

This flanged pipe was attached to the casting by means of six eye-bolts. A ¾-inch pipe, 4 feet 6 inches long, was screwed into this casting. Each of these ¾-inch pipes was joined to the main pipe, which in turn connected with the water main and with the air reservoirs. The shut-off globe valves for water and air are shown on the pipes connecting the main pipe with the water main and with the air reservoirs. Two cast-iron cylinders, 6½ inches in diameter and 4 feet 8 inches long, formed the air-reservoirs. They were connected with a large air-tank, not shown, by means of the pipe shown in Fig. 1, a shut-off globe valve being placed between the air-tank and air-reservoirs.

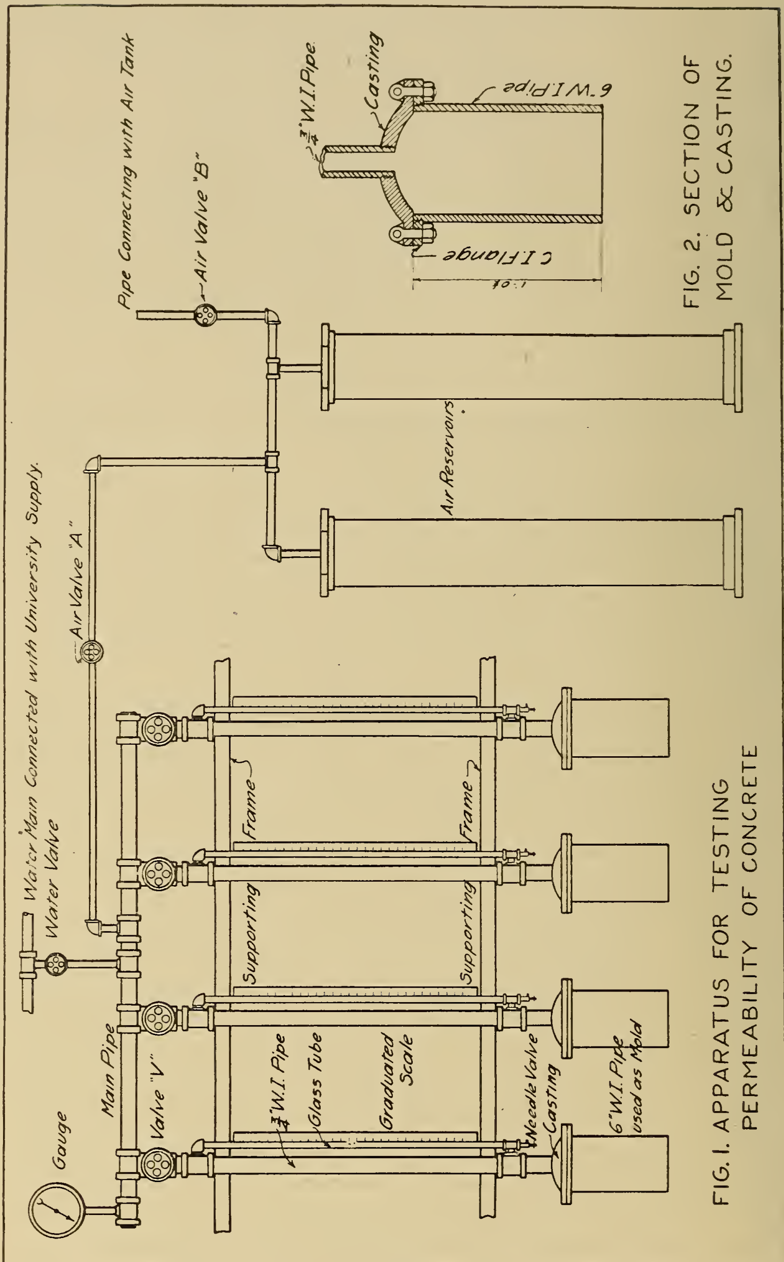

FIG. I. APPARATUS FOR TESTING PERMEABILITY OF CONCRETE

FIG. 2. SECTION OF MOLD & CASTING.

A glass tube and attached scale graduated to hundredths of feet, were fastened to each ¾-inch pipe in order to obtain the water level in the pipe. The globe valve "V" was used to disconnect any specimen proving defective. The ¾-inch pipe and glass tube were drained by means of the needle valve. A gage registered the air pressure.

Concrete:—The proportions by volume of the concrete were 1 : 3 : 5, the required amount of the materials being weighed on a scale. No attempt was made to secure a waterproof concrete by proper proportioning. On the contrary, a lean mixture was desirable in order to bring out the waterproofing qualities of the compounds.

Stone and Sand:—Local stone and sand and Atlas cement were used. The stone was a rather sandy lime-stone while the sand was of the fine bank variety. The mechanical analyses of the stone and sand are shown in Tables 1 and 2, respectively.

Water-proofing Compounds:—The compounds tested, which were all secured through local dealers in order to obtain the ordinary commercial product, were Century Cement Fluid, Dehydratine No. 4, Des Moines Elaterite No. 60, Hydrex Waterproof Felt and Compound, Limate, Medusa Waterproof Compound, Siastex Waterproofing Fabric No. 2 and Pitch, Universal Damp-Proof Compound, Aquabar, Antihydro, Antihydrine, Wunner's Bitumen-Emulsion, Coatine, and Flexible Compound. In nearly all cases the manufacturers, at our request, gave special instructions in regard to methods of waterproofing against the pressures used, such instructions being usually followed in the tests. As the name indicates Universal Damp-Proof Compound is used for damp proofing and not for waterproofing.

IV. METHOD OF MAKING THE SPECIMENS AND OF PERFORMING THE TESTS

Making the Specimens:—Materials sufficient for two specimens were first weighed out. The sand was spread out evenly on the mixing floor and upon this was placed the cement in a thin layer. Two men with shovels mixed the sand and cement thoroughly to an even color when a crater was made in the center which was filled with water. After the water was absorbed the mass was turned several times until the mortar was in the form of a thick paste. The stone which had previously been dampened was now spread over the mortar and the whole turned by two men with shovels for five minutes, water being added at times with a sprinkler. The consistency of the concrete was such that it flowed readily from a pile on the floor. A quantity of neat cement was now mixed with sufficient water to form a thick paste.

The six-inch pipe was placed on the floor with flanged-end up and a loose fitting wood disk ½ inch in thickness was dropped into it. A wrought iron pipe 4½ inches in diameter and 5 inches long, which had been turned on the outside to a taper, was centered on the wood disk. A lining of neat cement paste varying from 6/10 to 7/10 inches in thickness was now tamped into the annular space between the pipes, care being taken to fill the grooves in the outside pipe. This lining was carried up to within one inch of the top of the inner pipe, which was then filled with concrete to the level of the cement lining, the concrete being tamped well with a trowel meanwhile. The inner pipe was now carefully drawn upward about three inches, and the cement lining and concrete were deposited as before. This operation was continued until the specimen was completed, the depth of concrete being about 12 inches. The manner of finishing the upper surface varied for the different types of specimens and will be described later.

The cement lining and grooves were very effective in preventing water from seeping along the surface of the pipe. This was shown by chipping out the concrete and the lining of several specimens that had been subjected to pressure. While damp spots were found here and there in the pipe, in no case were they continuous. Neither was there any unusual flow between the concrete and the cement lining.

A set of 8 specimens was usually made for each kind of waterproofing, 4 of the specimens being tested at a pressure of 40 lbs/in^2 and 4 at a pressure of 20 lbs/in^2. All specimens were first tested at pressure of 40 lbs/in^2, and, if satisfactory, no other specimens were made. The duration of the tests was about 3 days, although the time was extended to 7 or 10 days in a few cases. In order to prevent shrinkage cracks, the specimens were covered with damp cloths for a few days after being made. The specimens were stored in air and were 35 days old when tested. The pressure was at all times applied to the upper or waterproofed surface of the concrete.

Performing the Tests:—The specimens were securely bolted to the castings, an Eclipse rubber gasket being used between the finished faces of flange and casting. With the air valve "A" closed and the air valve "B" opened, air was admitted to the reservoirs until sufficient pressure was obtained. The water-valve was opened and water was allowed to fill the ¾-inch tubes. Care was taken that the pressure did not exceed that used in the test, this being regulated by opening the needle-valves. Air-valve "B" was closed and air-valve "A" connecting with the air reservoirs was opened, thus subjecting the specimens to pressure. Usually it was necessary to drain the ¾-inch pipes through the needle valves until the water level was visible in the glass tubes.

The rate of flow of the water through the concrete was obtained by noting the scale readings and the time. Pressures were also noted, but they showed very little decrease as the volume of the air-reservoirs was very large compared to the volume of the ¾-inch pipes. No readings were taken for five minutes after the pressure was on. As the rate of flow rapidly decreased readings were taken at intervals of 10 or 15 minutes for the first few hours and then at intervals gradually increasing from 2 to 8 hours. The bottoms of the specimens were frequently examined and any dampness noted.

The threaded joint between the 6-inch pipe and the flange was the only unsatisfactory part of the apparatus. In some specimens considerable leakage was noticed at this joint, the cause no doubt being due to the springing of the joint when bolting the flange to the casting. When readings were taken these joints were always carefully examined and any leaks noted. The effect of this leakage has been eliminated as much as possible in reducing the data. Occasionally it has been necessary to throw out the entire set of readings on a specimen. This defect may doubtless be remedied by using a heavier flange.

V. RESULTS OF EXPERIMENTS

The compounds that were tested may be classified as follows according to the manner in which they were used:

(1) Compounds that were applied to the surface of the concrete. These may be sub-divided into three classes: (a) Compounds which were applied as surface paints, as Century Cement Fluid, Des Moines Elaterite No. 60, Universal Damp-Proof Compound, Antihydrine, and Flexible Compound. (b) Compounds which were applied in layers of felt, burlap, or tarred paper with a cementing material, as Hydrex Waterproof Felt and Compound, Siastex Waterproofing Fabric No. 2 and Pitch, and Dehydratine No. 4 and common tarred roofing paper. (c) Coatine which is a surface coating used in the form of a thick layer.

(2) Foreign ingredients that were added to the body of the concrete as Limate, Medusa Water-Proof Compound, and Aquabar.

(3) Foreign ingredients that were added to a mortar coating as Medusa Water-Proof Compound, Aquabar, Antihydro and Wunner's Bitumen–Emulsion.

A set of specimens was made using for waterproofing an ordinary mortar coating and a neat cement wash, this method of waterproofing being frequently made use of in reservoirs under a low head. In order to determine the effectiveness of waterproofing materials in general, a set of specimens was made in which the concrete was not waterproofed.

Different methods, as illustrated in Fig. 3, were used in finishing the upper surface of the specimens, depending upon the kind of waterproofing compound used. As shown at A and B in Fig. 3, the concrete was finished flush with the top of the pipe, the upper surface of the concrete being well troweled. Before troweling, the specimens were allowed to stand a half hour in order that the free water on the concrete might be absorbed.

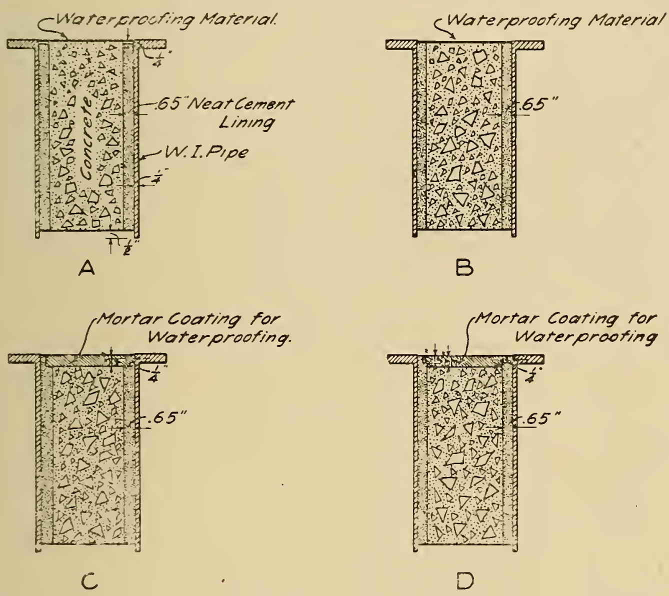

FIG. 3. SHOWING METHOD OF FINISHING UPPER SURFACE OF CONCRETE.

The cement lining extends to the top of the concrete in B, while in A it is cut off ¼ inch below. In the specimens that were coated with mortar (see C and D of Fig. 3) the surface of the concrete was ¾ of an inch below the top of the pipe. After the concrete had absorbed the standing water the mortar top was added, the surface of the concrete and the mortar being thoroughly troweled.

In Tables III to XVI, inclusive, are tabulated the results of the tests. In column 1 is given the time in hours counted from the beginning of the test and in columns 2, 3, 4 and 5 the corresponding flow for the different specimens in millionths of cu. ft. of water per sq. ft. of concrete surface. The corresponding flow in pounds of water may be obtained by multiplying the values in the columns by the constant .0000102. Tables III, IV, VI, VIII, XI, XII, XIV and XVI show only a part of the data because of the length of the test but the data selected is typical.

The experiments will be discussed in the same order in which the waterproofing compounds have been considered. In applying all surface preparations care was taken to secure a dry clean surface and to have the preparation well brushed in.

Century Cement Fluid:—This is a gray substance resembling caked putty, which was thinned with benzine to the consistency of a thick cream before being used. It is sold by the Century Cement Fluid Co., Madisonville, Ohio. The compound was applied in three coats with a brush at the ages of 14, 24 and 30 days. Only four specimens of the type shown at B in Fig. 3 were made because of a lack of time. These were subjected to a pressure of approximately 20 lbs/in² for 263 hours and no appreciable flow was noted.

Des Moines Elaterite No. 60:—This is a black tar-like liquid furnished by The Elaterite Paint & Manufacturing Co., Des Moines, Iowa. It is of the consistency of linseed oil and was applied cold. Eight specimens were made similar to that shown at B in Fig. 3. Three coats of the compound were applied at the age of 15, 23 and 31 days for the specimens tested at 20 lbs/in² and at the age of 10, 17 and 23 days, for those at 40 lbs/in². The specimens subjected to a pressure of 20 lbs/in² showed no measurable flow during the 72 hours that they were under pressure. The flow of the specimens subjected to a pressure of 40 lbs/in² was quite variable. (See Table III.) The duration of the test was 68 hours. Specimen No. 53 was practically impermeable, the flow of No. 54 and No. 52 was moderate but No. 51 showed excessive flow. While considerable leakage was noted at the flanged joint of No. 51 and No. 52, this leakage would not account for the increased flow of No. 51. Furthermore, while the bottoms of No. 53 and No. 54 were dry at the end of the test, the bottom of No. 51 was wet and that of No. 52 was damp.

Universal Damp-Proof Compound:—This is a heavy tar-like paint which was secured from the Universal Compound Co., No. 88 Maiden Lane, New York City. The 8 specimens were of the type sketched at B in Fig. 3. The compound was applied at the age of 15, 23 and 30 days for the pressure of 21 lbs/in^2 and at the age of 10, 16 and 26 days for the high pressure specimens. As will be seen by referring to Table IV the results at the 20 lbs/in^2 pressure for a period of 251.5 hours were satisfactory but extremely variable. Specimens No. 127 and No. 130 were practically impermeable, while specimens No. 128 and No. 129 showed moderate flow. Three of the four specimens that were tested at a pressure varying from 35 lbs/in^2 to 37 lbs/in^2 showed excessive flow, while considerable water entered the fourth specimen. (See Table V.) Moisture was noted on the bottom of No. 57 within 6 hours after the pressure was on, while No. 58 and No. 56 were wet within 16 hours. Specimen No. 59 remained dry on the bottom during the test which continued for 69 hours. This compound was unsatisfactory at this high pressure.

Antihydrine:—This compound is manufactured by The Antihydrine Company, New Haven, Conn. It is thin tar-like liquid which is applied cold. Because of a lack of time only 4 specimens of the type shown at B in Fig. 3. were made. Three coats of Antihydrine were applied at the age of 15, 23 and 31 days. Under a pressure of 20½ lbs/in^2 one of the specimens was impermeable, while the flow for the remaining three was moderate. All the specimens were dry on the bottom at the end of the test, which lasted about 168 hours. (See Table VI.) These specimens were removed from the apparatus and stored for 26 days when they were tested at a pressure of 40 lbs/in^2 for 79 hours. As will be seen by referring to Table VII the flow for each of the specimens was very small.

Flexible Compound:—This material, which resembles linseed oil in color and consistency, was secured from S. P. Holmes & Co., Chicago, Ill. Before applying the compound it was mixed with white lead, the proportions being 25 pounds of lead to one gallon of the compound, the mixture being of a creamy consistency. A set of specimens was made similar to that shown in Fig. 3 at B. Three coats of the waterproofing were used; applied at the age of 15, 23 and 30 days for the low and at 10, 16 and 26 days for the high pressure specimens. The results at each pressure were very satisfactory (see Tables VIII and IX), the flow being small and uniform. The first set of specimens was tested at a pressure of approximately 21 lbs/in^2 for 251.5 hours. and the second set at a pressure varying from 35 lbs/in^2 to 37 lbs/in^2 for 69 hours.

Hydrex Waterproof Felt and Compound:—These materials were purchased from the Hydrex Felt and Engineering Co., New York City. Four specimens, similar to those shown in Fig. 3 at A, were treated with these compounds at the age of 19 days. The compound was heated so that it ran readily from a stick and was then quickly applied with a swab in an even layer to the upper surface of the concrete. A sheet of felt was now placed on the compound and well smoothed with a brush. Alternate layers of compound and felt were applied until the specimen was covered with three thicknesses of felt and four layers of the compound. The sheets of felt were of sufficient size to extend outside of the flange. This waterproofing gave excellent results, the specimens showing no flow whatever when subjected to a pressure of 40 lbs/in^2 for 163 hours.

Siastex Waterproofing Fabric No. 2 and Pitch:—These materials were obtained from the Sicilian Asphalt Paving Co., New York City. The form of specimen used and the manner of applying the waterproofing were exactly the same as for Hydrex Waterproofing Felt and Compound. The specimens were treated at the age of 11 days. The test continued for 68 hours at a pressure of 39 lbs/in^2 and the specimens showed no permeability whatever.

Dehydratine No. 4 and Tarred Roofing Paper:—Dehydratine No. 4 is manufactured by the A. C. Horn Co., New York City. It is a black tar-like liquid of medium consistency which was applied cold. Tarred roofing paper similar to that found in ordinary building construction was used with this compound.

The four specimens were of the type sketched at A in Fig. 3, and the materials were applied in the same manner as was the Hydrex Felt and Compound with this exception. Two coats of Dehydratine were applied to the surface of the specimens and to the upper sheet of roofing paper, the first coat being quite dry when the second coat was added. As will be seen by referring to Table X the flow at a pressure of 40 lbs/in² was practically zero for the 66 hours that the test continued.

Coatine:—This is a gray fibrous material resembling soft putty and was obtained from the H. B. Morgan Co., Grand Crossing, Chicago. It does not appear to harden and was still quite plastic 35 days after applying. Eight specimens were made of the form shown at D in Fig. 3 but with Coatine used in place of mortar. In order to secure adhesion between the Coatine and the concrete and cement lining, the surface of the latter was roughened with a trowel and allowed to set thoroughly before the Coatine was applied. The layer of Coatine was placed on the specimens at the age of 5 days, care being taken to secure a good joint by proper troweling. Table XI shows the flow for three specimens at a pressure of 20 lbs/in² for 74 hours. Specimen No. 193 was impermeable while No. 192 and No. 195 gave a very slight flow. In Table XII are given the results for the specimens tested at an average pressure of 38 lbs/in². Specimen No. 200 was impermeable, No. 202 practically so, while No. 203 showed a slight flow and No. 201 a moderate flow. However, the needle valve of No. 201 leaked throughout the test, and this will account in part for the increased flow of the specimen.

Antihydro:—This is a thin liquid, greasy in consistency and containing a brown sediment. It was secured from the F. M. Hausling Co., New York City. Eight specimens were made of the type shown at D in Fig. 3. After the concrete had absorbed the water standing on its surface, the mortar coating was applied in three parts, the total thickness being ¾ of an inch. The concrete was first covered with a slush coat or grout of neat cement to a thickness of ⅛ of an inch. This was followed by a scratch coat of mortar ¼ to ⅜ of an inch thick, the proportions being one part of cement to two parts of sand. After the initial setting of the scratch coat, the finish coat of mortar was applied, its thickness being ¼ to ⅜ of an inch and the proportions one part of cement to one part of sand. Each coating was gaged with a mixture of water and Antihydro, the proportions by volume being one part of Antihydro to 10 parts of water. Care was taken to thoroughly trowel each coating. The results at a pressure of 40 lbs/in^2 were quite satisfactory as will be seen by referring to Table XIII. The flow was small and uniform for the different specimens. With the exception of specimen No. 190, which showed leakage at the flange joint (see Table XIV), the specimens were practically impermeable for a pressure of 20 lbs/in^2 when continued for 141 hours.

Plain Mortar:—Eight specimens were made similar to that sketched at C in Fig. 3. A ¾-inch mortar coat of the proportions, 1 part cement to 1½ parts sand, was applied to the concrete, the mortar being well troweled. At the age of 14 and 23 days the surface of each specimen was painted with a coating of neat cement of a creamy consistency. The cement and mixing water were not treated with any waterproofing compounds. Three of the specimens that were tested at a pressure of 39 lbs/in^2 (see Table XV) gave satisfactory results. Specimen No. 66 showed excessive flow, dampness being noted on the bottom 24 hours after pressure was applied. The flow was moderate for the three specimens that were subjected to a pressure of 19½ lbs/in^2 (see Table XVI). Owing to defective apparatus it was not possible to test specimen No. 135.

Tests at pressures of 40 lbs/in^2 and 20 lbs/in^2 were also made on Medusa Water-Proof Compound, Limate, Aquabar, Wunner's Bitumen-Emulsion and plain concrete, but the results obtained were conflicting. Additional tests on these materials are desirable.

However, these two facts were brought out:

1. That when Medusa Water-Proof Compound, Limate and Aquabar were added to the body of the concrete and not in the form of a mortar coating, unsatisfactory results were obtained in 45 out of 48 specimens.

2. That all specimens of plain concrete were wet on the bottom either before or at the end of 3 days, thus showing the effectiveness of some of the waterproofings discussed in this bulletin.

VI. COMPRESSION TESTS ON CONCRETE.

Concrete:—The proportions by volume of the concrete were 1 : 3 : 5. The cement, sand, and stone used were the same that were described under the permeability tests. The concrete was machine-mixed, the following method being used except in the case of Medusa Water-Proof Compound. Sufficient sand, cement, and stone were weighed on a scale to make 2½ cu. ft. of concrete. The sand and cement were thrown into the mixer in the order named. The mixer was run about one minute, sufficient water being slowly added to form a stiff mortar. The stone was now dumped into the mixer and the whole mass turned for 1½ minutes, the water being again gradually added until the concrete was of a wet consistency.

Waterproofing Compounds:—The compounds tested were Limate, Medusa Water-Proof Compound, and Aquabar.

Making of Specimens:—The compression specimens were of a cylindrical form, 6 inches in diameter and 18 inches high, cast iron molds being used. After the molds were set up on a horizontal plate, the concrete was deposited in them in layers, it being well stirred with a steel rod. Sufficient concrete was used so that after settling, its surface was slightly below the top of the cylinder. In a few days the upper surface of the concrete was plastered with 1 : 1 mortar, the surface of the mortar being finished flush with the top of the cylinder. Cylinders treated with each of the waterproofing compounds were made with 6 in each set, and 8 cylinders of plain concrete were made.

Performing the Tests:—The cylinders were broken in a Riehlé Universal testing-machine of 100,000 lbs. capacity at the ages of 35, 62, and 292 days. Three sheets of blotting paper were used at the tops and bottoms of the specimens when tested.

Results of Experiments:—In Table XVII are given the results of the tests which will now be considered.

(a) *Plain Concrete:*—For some unexplained reason the strength of the plain concrete specimens, marked P, is about 6 per cent less at 292 days than at 62 days.

(b) *Limate:*—This material is a hydrated lime obtained from the Western Lime and Cement Co., Milwaukee, Wis. Four sets of specimens were made, the ratio by weight of Limate to the cement for the different cylinders being 10 per cent, 14 per cent, 18 per cent and 22 per cent, respectively. In each case the Limate replaced an equal weight of the cement. The Limate and cement were first thoroughly mixed dry by hand. This mixture with the sand was then thrown into the mixer and the mixing process carried on as before described. The specimens marked L10, L14, etc. (see Table XVII) indicate those in which the Limate is equal to 10 per cent, 14 per cent, etc. of the weight of the cement. As shown in this table, the use of Limate usually increased the strength of the concrete, this effect being especially marked with the L10 and L14 specimens.

(c) *Medusa Water-Proof Compound:*—This is a dry powder furnished by the Sandusky Portland Cement Co. of Sandusky, Ohio. A quantity of the compound equal to 2 per cent of the weight of the cement was thoroughly mixed dry with the cement. Water was slowly added to this mixture while at the same time it was well troweled. The addition of water and the troweling were continued until the mixture was of a damp consistency. It was now thrown into the mixer with the sand, and the mixing completed as before outlined. By referring to Table XVII it will be seen that the cylinders (mark M) treated with this compound were stronger than those of plain concrete at corresponding ages. Furthermore, there is a decided increase in strength with age.

(d) *Aquabar:*—This compound was obtained from the Aquabar Co., Philadelphia, Pa. This is a material in gelatine form which, when properly diluted, is used to temper the mortar or concrete. The compound was thoroughly mixed with water in the proportions of 2 gallons of the compound to 48 gallons of water. The concrete for these cylinders was mixed as before explained with this exception, that the Aquabar solution instead of water was used to temper the mortar and the concrete. The results (see Table XVII) were very unsatisfactory, the Aquabar specimens (mark Aq) showing from 46 per cent to 64 per cent of the strength of plain concrete at corresponding ages.

TABLE 1.

Analysis of Local Limestone.

Per cent Voids=43.5. Wt. per cu. ft.=90.5 lbs.

Diameter of Mesh, ins.	Amount Retained, lbs.	Per cent Passing.
1.25	0	100
1.00	1.0	97.6
.75	2.5	91.6
.50	15.0	55.6
.33	11.0	29.4
.25	2.25	25.0
.14	4.5	13.2
Residue	5.5	10.8

TABLE II.

Analysis of Sand.

Per cent Voids = 37. Wt. per cu. ft. = 94½ lbs.

Sieve Number.	Diameter of Mesh.	Per cent Passing.
¼″	.25	100
6	.131	99.5
10	.073	94.3
16	.042	87.5
20	.034	83.9
30	.022	70.0
40	.015	58.0
50	.011	26.0
74	.0078	19.5
100	.0045	6.7

TABLE III.

PERMEABILITY OF CONCRETE SPECIMENS TREATED WITH DES MOINES ELATERITE NO. 60.

Pressure, 40 lbs/in². Age, 35 days.

TIME IN HOURS FROM BEGINNING OF TEST.	FLOW IN MILLIONTHS OF CU. FT. OF WATER PER SQ. FT. OF CONCRETE SURFACE.				REMARKS.
	No. 53.	No. 54.	No. 51.	No. 52.	
0.0	0	0	Apparatus not in order.	0	
0.2	0	130		0	
1.3	0	530		0	
3.3	130	930		0	
4.1	130	1060		130	No. 52 leaking.
14.3	530	3440		530	" " "
15.9	530	3580	0	930	No. 51 leaking.
16.8	530	3980	3180	1460	
20.9	530	4500	4510	4110	" " "
25.7	530	5040	5430	6500	
26.7	530	5160	5570	6630	No. 52 leaking.
36.9	530	5960	6760	7020	" " "
41.2	530	6230	8090	7160	
46.7	530	6500	9550	7820	
50.2	530	6630	12590	8880	" " "
60.7	530	7160	22800	10200	
67.9	530	7550	27800	10600	No. 51 wet on bottom. No. 52 damp on bottom

TABLE IV.

Permeability of Concrete Specimens Treated with Universal Damp-Proof Compound.

Pressure 21 lbs /in^2. Age, 35 days.

Time in Hours from Beginning of Test.	Flow in Millionths of Cu. Ft. of Water per Sq. Ft. of Concrete Surface.				Remarks.
	No. 128.	No. 129.	No. 130.	No. 127.	
0.0	0	0		0	Small leak in No. 128 & 129.
0.3	0	115		0	
1.0	230	345		0	
11.3	3680	2740		230	Small leak in No. 129.
16.4	4370	3450		345	" " " " "
20.5	4720	4140		460	" " " " "
24.8	5060	4950		575	
40.4	5980	7140		805	
50.5	6440	8050	No flow	920	
63.5	6790	9090		920	" " " " "
84.0	7360	10340		1035	
10[illegible].3	7940	11500		1035	
131.5	8290	12400		1035	
155.5	8630	12880		1150	
179.5	8860	13100		1150	
203.8	9090	13210		1150	
227.5	9440	13330		1150	
251.5	9550	13330		1150	

TABLE V.

PERMEABILITY OF CONCRETE SPECIMENS TREATED WITH UNIVERSAL DAMP-PROOF COMPOUND.

Pressure, 36 lbs/in². Age, 35 days.

Time in Hours from Beginning of Test.	Flow in Millionths of Cu. Ft. of Water per Sq. Ft. of Concrete Surface.				Remarks.
	No. 57.	No. 58.	No. 56.	No. 59.	
0.0	0	0	0	0	
0.4	1720	130	1720	0	
1.0	5570	795	1720	265	
2.9	14430	1325	3180	530	
5.9	27500	17100	16300	2520	No. 56 leaking freely. No. 57 wet on bottom.
15.7	43100	38300	39200	15620	No. 56 leaking freely. No. 56 & No. 58 wet on bottom.
19.9	48000	43200	43900	19090	
28.4	55900	5 000	Shut off specimen because of leakage of apparatus.	24500	
39.2	63500	59400		31200	
43.6	66000	61900		32350	
46.7	67500	63500		33550	
48.3	68600	64300		34100	
62.5	76100	71700		39800	
67.5	78400	73850		41500	
69.3	79000	74500		42000	

TABLE VI.

PERMEABILITY OF CONCRETE SPECIMENS TREATED WITH ANTIHYDRINE.

Pressure, 20½ lbs/in². Age, 35 days.

Time in Hours from Beginning of Test.	Flow in Millionths of Cu. Ft. of Water per Sq. Ft. of Concrete Surface.				Remarks.
	No. 175.	No. 176.	No. 177.	No. 178.	
0.0	0	No flow.	0	0	
0.2	0		0	0	
0.4	0		130	0	
1.3	0		265	0	
1.6	130		400	0	
.7	400		660	530	
15.6	1855		1325	1855	No. 178 leaking,
27.7	3180		1990	2920	
39.5	3840		2780	3710	
49.7	4110		3180	4240	
63.9	4510		3710	4910	
84.3	4770		3980	5560	
107.5	5300		4110	6360	
132.5	5970		4770	7560	
156.1	6500		4910	7950	
179.7	6900		5040	8210	
204.2	7160		5300	8750	
227.9	7700		5560	9290	

TABLE VII.

PERMEABILITY OF CONCRETE SPECIMENS TREATED WITH ANTIHYDRINE.

Pressure, 40 lbs /in^2. Age, 64 days.

Time in Hours from Beginning of Test.	Flow in Millionths of Cu. Ft. of Water per Sq. Ft. of Concrete Surface.				Remarks.
	No. 178.	No. 177.	No. 175.	No. 176.	
0.0	0	0	0	0	
0.2	0	0	0	0	
1.0	0	0	0	115	
1.8	0	115	0	115	
6.6	230	115	460	230	No. 175 leaking.
25.8	920	920	2070	690	" " "
31.3	1150	1035	2300	805	
47.3	1610	1380	2760	1265	
55.3	1840	1610	2990	1495	
73.8	2300	1840	3450	2070	
79.1	2530	1955	3565	2185	

TABLE VIII.

PERMEABILITY OF CONCRETE SPECIMENS TREATED WITH FLEXIBLE COMPOUND AND WHITE LEAD.

Pressure, 21 lbs/in². Age, 35 days.

Time in Hours from Beginning of Test.	Flow in Millionths of Cu. Ft. of Water per Sq. Ft. of Concrete Surface.				Remarks.
	No. 132.	No. 133.	No. 134.	No. 131.	
0.0	0	0	0	0	
0.3	130	0	0	130	
1.0	400	0	0	130	
11.3	1190	400	530	530	
16.4	1190	530	660	660	
20.5	1325	530	795	660	
24.8	1460	795	930	795	
40.4	1720	1190	1460	1060	
50.5	1720	1325	1590	190	
63.5	1990	1590	1855	1325	
84.0	2250	2120	2385	1590	
108.3	2520	2650	2920	1990	
131.5	2780	3040	3180	2250	
155.5	3050	3440	3440	2520	
179.5	3320	3840	3980	2650	
203.8	3580	4240	4370	2915	
227.5	3840	4510	4760	3180	
251.5	3980	49 0	5160	3310	

TABLE IX.

PERMEABILITY OF CONCRETE SPECIMENS TREATED WIEH FLEXIBLE COMPOUND AND WHITE LEAD.

Pressure, 36 lbs/in². Age, 35 days.

Time in Hours from Beginning of Test.	Flow in Millionths of Cu. Ft. of Water per Sq. Ft. of Concrete Surface.				Remarks.
	No. 62.	No. 6[illegible].	No. 61.	No. 55.	
0.0	0	0	0	0	
0.4	230	0	0	230	
1.0	230	0	0	460	
2.9	690	0	0	805	
5.9	1035	230	115	1380	
15.7	1840	345	230	2760	
19.9	2185	575	345	3335	
28.4	2875	920	345	4140	
39.2	3680	1380	575	5290	
43.6	4025	1610	575	5635	
46.7	4255	1725	575	5980	
48.3	4370	1725	575	6095	
62.5	5405	2185	690	7245	
67.5	6210	2300	690	7590	
69.3	6555	2415	805	7820	

TABLE X.

Permeability of Concrete Specimens Treated with Dehydratine No. 4 and Tarred Roofing Paper.

Pressure, 40 lbs /in². Age, 35 days.

Time in Hours from Beginning of Test.	Flow in Millionths of Cu. Ft. of Water per Sq. Ft. of Concrete Surface.				Remarks.
	No. 110.	No. 107.	No. 108.	No. 109.	
0.0	0	0	No flow.	0	
0.5	0	0		0	
1.5	0	0		0	
2.8	0	0		0	
4.8	0	0		0	
14.3	230	0		115	
17.3	230	0		115	
20.0	230	0		115	
25.0	230	0		115	
30.4	230	0		115	
41.5	345	115		115	
44.0	460	230		230	
52.4	575	345		230	
64.0	690	345		345	
66.8	690	460		345	

TABLE XI.

PERMEABILITY OF CONCRETE SPECIMENS TREATED WITH COATINE.

Pressure, 20 lbs/in^2. Age, 35 Days.

Time in Hours from Beginning of Test.	Flow in Millionths of Cu. Ft. of Water Per Sq. Ft. of Concrete Surface.				Remarks.
	No. 192.	No. 194.	No. 193.	No. 195.	
0.0	0	No test made.	No flow.	0	
0.8	0			130	
1.1	130			130	
2.8	265			265	
4.2	400			265	
5.0	400			265	
6.0	400			265	
8.5	400			400	
20.9	665			530	
29.7	795			530	
32.4	795			665	
44.0	1060			795	
53.8	1190			1060	
56.5	1190			1060	
68.0	1190			1060	
74.0	1325			1060	

TABLE XII.

Permeability of Concrete Specimens Treated with Coatine.

Pressure, 38 lbs /in². Age, 35 days.

Time in Hours from Beginning of Test.	Flow in Millionths of Cu. Ft. of Water Per Sq. Ft. of Concrete Surface.				Remarks.
	No. 203.	No. 200.	No. 202.	No. 201.	
0.0	0	No flow.	0	0	
0.2	130		130	0	
0.8	130		265	130	
1.5	265		530	265	
5.0	530		795	1060	
8.8	530		795	1460	
22.5	530		795	2920	No. 201 leaking.
24.2	795		795	3050	No. 201 continued to leak throughout the test.
40.2	795		795	3580	
48.1	930		795	3840	
62.6	930		795	4110	
72.1	1195		795	4770	
96.9	1195		795	5960	
120.8	1460		795	7290	
144.7	1590		795	8210	

TABLE XIII.

PERMEABILITY OF CONCRETE SPECIMENS TREATED WITH ANTIHYDRO.

Pressure, 40 lbs/in². Age, 35 days.

Time in Hours from Beginning of Test.	Flow in Millionths of Cu. Ft. of Water per Sq. Ft. of Concrete Surface.				Remarks.
	No. 106.	No. 104.	No. 105.	No. 103.	
0.0	0	0	0	0	
0.5	930	660	460	1190	
1.5	1990	1590	1325	2250	
2.8	2520	1990	1720	2520	
4.8	2920	2250	2250	2780	
14.3	3320	2520	2915	3040	
17.3	3320	2520	3040	3040	
20.0	3320	2520	3040	3040	
25.0	3440	2520	3180	3040	Small leak in No. 105.
30.4	3440	2650	3310	3180	
41.5	3580	2650	3580	3310	" " " " "
44.0	3580	2650	3710	3310	" " " " "
52.4	3710	2650	4640	3440	" " " " "
64.0	3840	2720	5430	3580	" " " " "
66.8	3840	2720	5560	3580	

TABLE XIV.

Permeability of Concrete Specimens Treated with Antihydro.

Pressure, 20 lbs/in^2. Age, 35 days.

Time in Hours from Beginning of Test.	Flow in Millionths of Cu. Ft. of Water per Sq. Ft. of Concrete Surface.				Remarks.
	No. 189.	No. 191.	*No. 190.	No. 188.	
0.0	0	0	0	0	
0.2	345	345	460	345	
0.4	575	690	690	345	
0.8	920	920	1150	1265	
2.2	1380	1150	1725	1610	
3.7	1610	1150	1840	1840	
5.5	1725	1150	....	1955	
16.7	1955	1150	....	2300	
21.7	2070	1150	3220	2415	
26.2	2070	1150	3340	2415	
29.2	2070	1150	3450	2415	
40.6	2070	1150	3910	2415	
50.2	2070	1150	4260	2530	
64.7	2070	1150	4950	2530	
66.7	2070	1150	5060	2530	
140.8	2070	1150	5060	2530	

*No. 190 leaked throughout the test.

TABLE XV.

Permeability of Concrete Specimens Treated with Plain Mortar.

Pressure, 39 lbs/in². Age, 35 Days.

Time in Hours from Beginning of Test.	Flow in Millionths of Cu. Ft. of Water per Sq. Ft. of Concrete Surface.				Remarks.
	No. 63	No. 64.	No. 65.	No. 66.	
0.0	0	0	0	0	
0.4	805	460	460	1495	
1.7	1950	1380	1380	4370	
4.9	2530	1950	1840	9200	
14.9	3105	2640	2185	19200	
19.4	3340	2880	2300	24400	
24.2	3450	3110	2300	25250	No. 66 damp on bottom.
28.0	3450	3220	2415	27000	
37.4	3680	3450	2415	30400	No. 66 wet on bottom.
42.1	3680	3680	2415	31600	
47.8	3800	3800	2530	33000	
50.8	3800	3910	2530	33700	
62.1	3910	4140	2530	35900	
67.8	4030	4160	2530	36900	

TABLE XVI.

Permeability of Concrete Specimens Treated with Plain Mortar.

Pressure, 19½ lbs /in². Age, 35 days.

Time in Hours from Beginning of Test.	Flow in Millionths of Cu. Ft. of Water per Sq. Ft. of Concrete Surface.				Remarks.
	No. 135.	No. 136.	No. 137.	No. 138.	
0.0	Apparatus not in order.	0	Apparatus not in order.	0	
0.3		660		660	
0.8		660		1325	
1.2		795		1590	
3.0		1190		1990	
4.6		1460		2250	
5.9		1720	0	2520	
9.1		1850	1460	2780	
20.3		2120	1720	3440	
26.3		2250	1720	3710	
32.5		2250	1990	3710	
43.5		2250	2120	3980	
48.2		2250	2250	4110	
56.3		2250	2380	4240	
67.7		2250	2520	4510	
80.3		2250	2780	4770	
93.1		2250	2780	5040	

TABLE XVII.

Effect of Waterproofing Compounds on the Compressive Strength of 1 : 3 : 5 Concrete.

Specimens.	Ultimate Compressive Strength in Lbs / in².					
	Age, 35 days.		Age, 62 days.		Age, 292 days.	
		Average.		Average.		Average.
P	940	....	1110	....	1330	
P	780	....	1160	....	880	
P	....	....	....	....	930	
P	....	860	....	1135	1140	1070
Aq.	570	....	480	....	620	
Aq.	530	550	570	525	....	620
L10	1110	....	1200	....	1240	
L10	960	1035	1180	1190	1210	1225
L14	1130	....	1270	....	1130	
L14	1050	1090	1320	1295	1300	1215
L18	1040	....	1000	....	1040	
L18	860	950	1190	1095	1020	1030
L22	1000	....	1250	....	1340	
L22	750	875	10 .0	1140	1140	1240
M	970	....	1090	....	*1270	
M	890	930	1160	1125	1220	1245

*This specimen was broken by mistake at age of 224 days.

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